Geostationary Operational Environmental Satellite System (GOES)
GOES-R Sounder and
Imager
Cost/Benefit Analysis (CBA) – Phase III

Prepared for the
Department of Commerce

by

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January 2004

Executive Summary

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation Geostationary Operational Environmental Satellites (GOES), referred to as GOES-R, which are expected to provide significant advances in earth coverage and weather and environmental information and prediction capabilities. Two of the key instruments within this GOES suite of sensors are the Advanced Baseline Imager (ABI) and Hyperspectral Environmental Sounder (HES). To provide a firm foundation for the formulation of instrument development and procurement budgets, NOAA initiated an analysis of the marginal cost and benefit differences (in economic terms) between continuation of instruments with similar performance to today's imager and sounder and the planned GOES-R imager and sounder. Phases I and II of this analysis were conducted in 2001 and 2002, and are documented in a report entitled *Geostationary Operational Environmental Satellite System (GOES) GOES-R Sounder and Imager Cost/Benefit Analysis (CBA) – Phases I and II* located at http://www.osd.noaa.gov.

From a benefits perspective, selected case studies were developed that describe changes in economic impacts (i.e., marginal benefits) due to the proposed changes in the instruments. The expert knowledge and judgment of NOAA engineering staff, scientists, and product managers provided information on ABI and HES performance changes relative to the current imager and sounder and product improvements based on these performance changes. Information on economic benefits (primarily *avoided* costs) from these product improvements were obtained via public meetings, discussions, and interviews with GOES constituents and published literature and economic data pertaining to decisions based on this weather data. Published economic data used in the benefit analysis were not independently validated.

All costs are presented in fiscal year 2003 dollars, and the time frame under which the analysis is considered is 2012 to 2029 (17-year life cycle). It was assumed that the advanced imager and sounder instruments will be launched in mid-2012 through 2013 and the required infrastructure to make effective use of improved data from these instruments will be in place in the 2012 time frame. However, it was further assumed that benefits do not begin until 2015 to allow for delays in the launch of the full complement of new instruments; and lag time for model revision and testing to take advantage of and have more confidence in the improved instrument data. Time will be needed after launch, checkout, and calibration before better economic decisions are likely to commence based on the new data. There is a limit to how much can be done to modify forecast models and products prior to launch. Time is needed to complete these modifications, and to test, validate, and verify improvements in forecasts and other products using actual advanced imager and sounder data. It will also take time to educate users and constituents as to the improvements.

Summary of Results

This report documents Phase III of the Cost Benefit Analysis and describes the results of six case studies that address the commercial shipping, commercial fishing, golfing, and landscaping industries as well as lightning safety. Below is a qualitative overview of the benefits of each case addressed in Phase III. The results of the quantitative analysis are summarized in Table ES-1. The dollars are annual 2003 dollars and total discounted benefits for the 15-year effective life cycle. (The life cycle of 15 years has been adjusted to reflect the assumption that time will be needed to realize product improvements based on data from the new sensors.)

1. **Commercial Container Shipping: Reduced Cargo Loss, Transit Efficiency**. Commercial ships carry greater than 95 percent of the world's trade by weight. The annual value of U.S. containerized cargo alone is greater than $500 B. Eight three percent of all cargo losses are preventable. Benefits are realized from improved tropical cyclone track and intensity forecasts, leading to a reduction in container cargo loss and vessel transit-time savings.

2. **Commercial and Recreational Fishing: Increase in U.S. Landings**. The commercial fishing industry contributed $29 billion to the U.S. Gross National Product in 2002 for over 9 billion pounds landed. Recreational fishing has been estimated as contributing $37 billion in 2002. Fish population estimates are highly uncertain. Benefits are realized from reducing uncertainty of biomass estimates by incorporating more accurate environmental data, in particular sea surface temperature, into survey design. Less uncertainty in biomass estimates will result in more efficient fishing restriction decisions without harm to sustainability.
3. **Recreation: Improved Safety and More Efficient Ground Maintenance, Irrigation, and Planning**. The U.S. golf economy contributed over $62 billion to GDP in 2000 with greater than $20 billion from golf facility operations alone. Among golf courses reporting a decrease in rounds played from 2000 to 2001, 52 percent cited weather as the leading reason. Golf courses account for 1.5 percent of all fresh water usage in the U.S., consuming more than 5 billion gallons per day. Between 1959 and 1994, golf-related lightning strikes accounted for 5 percent of all lightning related deaths, injuries, or damages (NOAA). Benefits are realized from savings from improved irrigation efficiency (avoided irrigation costs); improved grounds maintenance—more effective timing of fertilizer/herbicide; better-informed tournament planning (or cancellations)/personal play scheduling and planning; and, reduced lightning-related golf deaths/injuries/property damage.
4. **Landscaping: More Efficient Irrigation and Ground Maintenance**. The dollar volume for the landscaping industry for 2002 was $52-$58 billion. Grounds care expenditures by the U.S. landscaping industry in 2001 totaled $2.47 billion. Landscaping accounts for 2.9 percent of all fresh water usage in the U.S., consuming nearly 10 billion gallons per day. Benefits are realized from improved wind speed, humidity, and precipitation forecasts that result in reduced excess irrigation and fewer wasted fertilizer/herbicide applications.
5. **Lightning Safety: Reduced Damage/Loss of Life.** In the U.S., approximately 25 million cloud to ground lightning flashes occur each year. Lightning, the second largest U.S. weather killer since 1960, caused an average 47 deaths, 303 injuries, and $39.5M in damages per year from 1998-2002. Research suggests that lightning costs and losses may reach $4-5 billion per year. Benefits are realized from improved forecast techniques and improved effectiveness of National Weather Service storm warnings and watches.

It is important to note that the case studies developed and presented in this paper represent just a sampling of economic sectors and domains from which economic benefits can be realized. The *total* potential marginal discounted benefits to the United States from GOES-R have not been estimated in this paper. However, the total annual marginal benefits from the five cases discussed in this report ($599B) added to the benefits computed in the Phase I and Phase II report ($875), show combined annual marginal economic benefits from ABI and HES are approximately $1.474 B annually (2003 dollars) and a discounted (present value) sum-of-direct benefits of approximately $7B across a 15-year effective benefit life cycle. The Office of Management and Budget (OMB) guidance in circular A-94 states that the criterion to be used to decide if an investment is economically justified is whether or not the estimated Net Present Value (NPV) is positive (greater than zero). To appropriately calculate the NPV, the present value of benefits must be reduced by the marginal costs for ABI and HES (that is, the costs over an above what it would cost to reproduce the current imager and sounder capability). These costs are currently being calculated.

Table ES-1. Advanced Imager and Sounder Benefits Analysis Results

Phase	Application/ Benefit Area	Incremental Annual Benefits $M (2003)	Present Value (discounted) Sum of Incremental Benefits $M (2003)**
Phases I & II*	Commercial Aviation	$ 56	$ 242
	Utilities – Electric Power	$ 451	$ 2,151
	Utilities – Natural Gas	$ 7	$ 29
	Agriculture	$ 40	$ 867
	Recreation – Boating	$ 29	$ 127
	Commercial Trucking	$ 28	$ 122
	Consumer Benefits – Drinking Water	$ 230	$ 1,000
	SUB TOTAL PHASES I & II	$ 841	$ 4,538
Phase III	Commercial Shipping	$ 93	$ 403
	Fishing (Commercial & Recreational)	$ 4	$ 17
	Recreation***	$ 186	$ 806
	Residential Landscaping	$ 291	$ 1,260
	Lightning Safety	$ 25	$ 108
	SUB TOTAL PHASE III	$ 599	$ 2,594
	TOTAL	$ 1,440	$ 7,132

* This refers to previous CBAs for GOES-R. See www.osd.noaa.gov.
**Present value estimates are for the years 2015 to 2029 and are not uniformly larger than marginal annual benefits because some benefit areas incorporate growth factors or assumptions about the rate of technology adoption. See Benefit Calculation section for details.
***Reduction in selected recreation-related fatalities, injuries and property damage due to lightning are included under "Lightning Safety."

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Section 1

GOES-R Cost/Benefit Analysis

1.1 Introduction

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation Geostationary Operational Environmental Satellites (GOES), referred to as GOES-R, which are expected to provide significant advances in earth coverage and weather and environmental information and prediction capabilities. Two of the key instruments within this GOES suite of sensors are the Advanced Baseline Imager (ABI) and Hyperspectral Environmental Sounder (HES). To provide a firm foundation for the formulation of instrument development and procurement budgets, NOAA initiated an analysis of the marginal cost and benefit differences (in economic terms) between continuation of instruments with similar performance to today's imager and sounder and the planned GOES-R imager and sounder. Phases I and II of this analysis were conducted in 2001 and 2002, and are documented in a report entitled *Geostationary Operational Environmental Satellite System (GOES) GOES-R Sounder and Imager Cost/Benefit Analysis (CBA) – Phases I and II* located at http://www.osd.noaa.gov. The background for this current study as well as a detailed description of the methodology used in this analysis are provided in the Phase I and II report and will not be repeated here.

From a benefits perspective, selected case studies were developed that describe changes in economic impacts (i.e., marginal benefits) due to the proposed changes in the instruments. The expert knowledge and judgment of NOAA engineering staff, scientists, and product managers provided information on ABI and HES performance changes relative to the current imager and sounder and product improvements based on these performance changes. Information on economic benefits (primarily *avoided* costs) from these product improvements were obtained via public meetings, discussions, and interviews with GOES constituents and published literature and economic data pertaining to decisions based on this weather data. Published economic data used in the benefit analysis were not independently validated.

A key factor in each of the case studies is the extent to which improved data and information from GOES-R could result in improved decisions and savings. The specific value for this factor varies considerably between case studies in this report because of the different circumstances posed by each case study domain. For example, in some domains a large proportion of economic decision makers already use the kind of products that GOES-R will potentially contribute to in order to make decisions on a very frequent basis—e.g. daily or even hourly. In these domains there is a very clear, direct, and compelling linkage between potential product improvements due to GOES-R and improved decisions, and a relatively large, but still conservative, factor can be used. In other domains, the use of improved products from GOES-R is more speculative, or the linkage from improved products to improved decisions is not as direct, or not as frequent, and we use a smaller, even minimal, factor in computing potential benefits.

All costs are presented in fiscal year 2003 dollars, and the time frame under which the analysis is considered is 2012 to 2029 (17-year life cycle). It was assumed that the advanced imager and sounder instruments will be launched in mid-2012 and the required infrastructure to make effective use of improved data from these instruments will be in place in the 2012 time frame. However, it was further assumed that benefits do not begin until 2015 to allow lag time for model revision and testing to take advantage of and have more confidence in the improved instrument data. Time will be needed after launch, checkout, and calibration before better economic decisions are likely to commence based on the new data. There is a limit to how much can be done to modify forecast models and products prior to launch. Time is needed to complete these modifications, and to test, validate, and verify improvements in forecasts and other products using actual advanced imager and sounder data. It will also take time to educate users and constituents as to the improvements.

Section 2

Benefits Analysis and Results

Benefits are received across a variety of application areas and to many individuals and organizations in the public and private sector. In general, benefits are derived from an improved ability to:

- Predict ***when*** and ***where*** severe weather will manifest itself;
- Predict farther ***in advance*** (increased lead time) when severe weather will occur;
- Predict, with ***improved accuracy***, the characteristics of severe weather initiation (e.g., temperature, humidity);
- Observe hazardous phenomena ***more clearly***, ***sooner,*** and with ***greater frequency*** from improved imagery;
- ***Track*** weather more accurately, and
- ***Observe*** the previously unobservable.

This section discusses individual case studies and the quantitative benefits associated with each.

Case Study 1: Commercial Container Cargo Shipping: Cargo Loss Prevention and Transit-Time Savings

Overview

The World Trade Organization (WTO) calculated world trade growth of 5.5 percent for the period 1990-2001 [World Trade Organization]. According to Thorpe (2002) a growth rate of 4-5 percent in international trade is expected to continue. The commercial shipping industry is a very important contributor to this growth rate. It is estimated that more than 90-95 percent of the world's international trade by weight is carried on commercial ships. For U.S. trade alone, more than 99 percent of cargo by weight moves by ship and is valued at $546 billion annually [NOAA, *Promote Safe Navigation*]. An efficient commercial shipping industry is a critical factor in the world economy.

Commercial Shipping Vessels

Maritime cargo travels the oceans on a variety of vessel types. Figure 1 displays the major vessel types according to their functional classification. Under the classification of general cargo are break bulk, neo-bulk, and containerized vessels. Break bulk vessels carry miscellaneous types of cargo packaged in their individual containers such as pallets, drums, sacks, or bags. Neo-bulk vessels carry discrete goods that are measured by counting, such as automobiles and timber. Containerized cargos are most often manufactured goods such as computers, automobile parts, retail products, and refrigerated cargo (carried on a refrigerated container, or "reefer"). Reefers carry such food products as frozen meat, fresh fruits, and dairy products.

Figure 1. Functional Classification of Marine Deep Sea Vessels

Bulk cargoes are non-packaged goods that travel in their natural state on a vessel. There are two types of bulk cargo: liquid bulk and dry bulk. Common liquid bulk cargoes are oil, liquefied natural gas, chemicals, and food products. Dry bulk cargo often consists of grains (such as wheat, corn, or soybeans), iron ore, and scrap metal. While dry bulk vessels remain as the largest in numbers of cargo carrying vessels, they often have much less cargo capacity than the specialized ships (for example, containerships) that are replacing them [Consultant's & Lobbyist's International Information, Ltd.].

Historically, nearly all cargo was carried in bulk prior to the onset of cargo containerization. Container shipping has become an increasingly dominant mode of transportation for much of the world's goods. Vickerman (2001) displays the *Maritime Reporter's* data detailing this trend in Figure 2. It can be seen from the figure that from 1980 to 2000 the proportion of all maritime cargo that was containerized has increased from 23 percent to 70 percent. This dramatic trend is expected to continue, with container traffic presumed to double during the period 2000-2010 [Thorpe]. Our focus for the remainder of this report will be on the commercial containership subset of the world commercial shipping industry.

Figure 2. The Containerization of Cargo During the Period 1980-200 (Projected Out to 2010).

Purpose

The commercial container shipping industry is highly competitive and extremely time sensitive. Shippers are under pressure to deliver cargo in the minimum time possible while maintaining crew and cargo safety. Some of the biggest uncertainties facing a shipper out of port are the environmental conditions that will be encountered along the open-ocean segment of the voyage. Shippers turn to both government and private companies expert in forecasting sea conditions and providing recommended shipping routes to help them get to their destinations safely and efficiently.

The purpose of this case study is to identify those areas of the commercial container shipping industry that can benefit from improved remote sensing data derived from improved GOES measurements and to estimate the economic benefits that can be realized from these improvements.

Methodology

GOES satellite measurements are an important observational data source that is input into numerical weather forecast models to forecast sea state (winds and waves) and recommend optimal shipping routes. Through the use of these optimal shipping routes, commercial container shippers can optimize their schedules and deliver their cargo quickly under the safest conditions possible.

The most prominently used product for ship routing is GOES feature (cloud) tracking winds (imager-based), which are input into models such as the Navy Operational Global Atmospheric Prediction System (NOGAPS) and NOAA's Aviation (AVN) and Eta models. Other GOES products useful for ship routing include Sea Surface Temperature (SST—both imager and sounder-based), Total Precipitable Water (TPW—sounder based), fog (imager-based), Lifted Index (sounder-based), and Cloud-Top Pressure (sounder-based) [GOES Products and Services Catalog].

NOAA's Marine Prediction Center (MPC) uses these GOES products for their surface forecasts, which depict the centers of synoptic-scale high- and low-pressure centers. The surface forecasts include location of fronts, troughs, ridges, areas of fog, and likely areas of freezing spray [National Weather Service]. In addition, the products are used in the wind/wave forecasts, which depict forecast wind vectors and significant wave heights. These parameters combine to benefit commercial container shippers by allowing ship routers to recommend routes that minimize exposure to heavy weather, strong currents, and high seas that might otherwise lengthen a ship's transit time, or cause damage to a ship's hull, cargo, or crew.

The GOES products mentioned above are based on current sensor (imager and sounder) performance. The prospect of the advanced imager and sounder with the next-generation GOES series of spacecraft offers substantially improved spatial resolution and temporal coverage, particularly helpful in data-sparse regions over the oceans.

For experiments performed during selected hurricanes in 2000 and 2001, GOES was operated in a rapid scanning mode, taking images of the storms at 1-minute intervals. Winds derived from these images using a feature (cloud) tracking technique showed that the quality of cloud-motion winds was greatly enhanced with the frequent sampling strategy [Berger]. The ABI on GOES-Next will provide images every 5 minutes for the continental United States (CONU.S.) and every 15 minutes for the full-disk, representing 3- and 12-fold improvements, respectively, over the current GOES imager performance characteristics.

Temperature and moisture changes derived from soundings over the Eastern Pacific, Gulf of Mexico, and Western Atlantic (monitored hourly with the current GOES sounders) play a critical role for marine forecasts [Menzel]. These soundings do well to fill the measurement gaps present in polar orbiter sounding and radiosonde coverage. However, the advanced GOES sounder will have a coverage rate five times that of the current GOES. The increased spatial and temporal resolution will fill these measurement gaps even better, helping to improve marine forecasts even further.

In summary, there exists clear evidence that improvements in GOES will help to improve marine forecasts of winds and waves. These improvements will enable commercial container shipping companies to make better-informed decisions about transporting their cargo around the world.

The approach taken in this report to estimate the average annual benefits for the commercial container shipping industry due to GOES-R involves two separate calculations. The first calculation estimates the benefits to be derived from container cargo loss prevention and the second calculation estimates the benefits to be derived from container vessel transit-time savings. It should be noted that these two calculations are not entirely independent of one another. These calculations are derived as follows:

Container Cargo Loss Prevention

1. Determine the number of annual containership transits to and from the Americas.
2. Estimate the total amount and value of containers lost on these transits.
3. Estimate the percentage of these losses that are a result of heavy weather.

4. Estimate the percentage of the losses due to heavy weather that could have been prevented with improved GOES-R data.
5. Estimate the preventable container cargo losses due to improved GOES-R data.

Transit-Time Savings

1. Determine the likely range of hourly operating costs of a "typical" containership.
2. Estimate the potential range of hours saved due to GOES-R on both Trans-Atlantic and Trans-Pacific crossings.
3. Estimate the total value of transit-time savings for the commercial container shipping industry due to improved GOES-R data

Finally, estimate the total average annual benefit to the commercial container shipping industry due to GOES-R by summing the results from the container cargo loss prevention calculation with the results of the transit-time savings and calculate the present value (PV).

Commercial Container Shipping Industry

Container shipping refers to the transport of reusable, standard-size containers on specially designed vessels. Containerships are characterized by their container capacity, expressed in TEU[1]. One cargo container is equal to one TEU. In 2000, the number of containers that moved through U.S. ports totaled 17 million TEU, or about two-thirds of U.S. ocean borne trade by value [Smith]. These figures equate to over 45,000 containers handled per day [Richardson]. The value of containerized cargo that landed in the U.S. ports in 2001 was over $500 billion [United States Maritime Administration]. This is estimated to increase to over $765 billion by the year 2010 [Richardson].

Containerization of cargo was first introduced in 1955 by Malcolm McLean, founder of Sea-Land Service, Inc., with the idea of decreasing the amount of time cargo spent in port [Talley]. McLean conceived the idea of moving cargo in the same container through various modes of transport (including sea, land, and rail), with minimum time spent in transferring cargo between modes. This type of transport is known as *intermodalism*, and it caught on extremely well due to its highly efficient movement and minimal handling of cargo. Rapid expansion followed the introduction of containerized shipping in the 1970s and 1980s, so much so, that containerized shipping is now the dominant mode for transporting non-bulk cargo over the oceans [Smith].

Container Cargo Loss Prevention for Containerships

Worldwide, cargo containerships carry over one hundred million containers successfully to their destinations annually [Storandt]. However,, a significant number of containers are lost overboard each year. According to the Canadian Board of Maritime Underwriters Association, approximately 83 percent of all cargo losses are preventable, and approximately 45 percent of preventable losses are due to poor handling and stowage of cargo [The Mariport Group, Ltd.]. The remaining 55 percent of preventable losses have causes that include theft, water damage, and fortuitous loss. Fortuitous losses can include sinkings, strandings, fire, collisions, and heavy weather [The Mariport Group, Ltd.]. In this report, we focus on those preventable losses that result from heavy weather.

As stated above, cargo is lost overboard from ships on a regular basis. In many instances, small numbers of containers are lost overboard, but there are also larger events where as many as several hundred containers are lost. The largest incident on record is known as the "APL China" casualty of 1998, in which more than eight hundred containers were lost or damaged. It is thought, however, that the majority of these incidents go unreported due to the fact that private shipping companies have little incentive to report lost cargo because the losses are reimbursed by insurance and no legal responsibility is ever assessed for leaving the lost cargo behind [Storandt].

The relatively few instances of containerized cargo losses that actually do get reported are compiled in the reference **www.aimu.org/ondeckstorage.html**. This compilation of cargo lost or damaged during the period 1989-2000 is shown below in Table 1.

Table 1. Casualty List of Containers Lost Overboard 1989-2000

To estimate the total cargo losses in a given year (both reported and non-reported), it is necessary to begin with the total number of worldwide containership transits. Kite-Powell (2000) provides an estimate of the average number of containership ocean transits per year on the world's three major trade routes, the Americas to Europe, the Americas to Asia, and Europe to Asia, shown in Table 2.

[1] A TEU is a standard unit of measure for container cargo. A TEU, or "twenty-foot equivalent unit" is a container that measures 20 feet in length, 8 feet in height, and 8 feet in width. Most large vessels actually carry primarily FEUs, or "forty-foot equivalent unit," but the cargo capacity is still listed in TEU.

Table 2. Approximate Number of Annual Ocean Transits of Containerships on Major Trade Routes in 2000 *(subset of Table 3 in Kite-Powell (2000))*.

Route	Ocean Crossing	Approximate annual ocean transits
Americas – Europe	Atlantic	4,000
Americas – Asia	Pacific	6,000
Europe – Asia	Indian	6,500
	Total	16,500

As seen in the above table, the approximate number of annual ocean transits for containerships worldwide is 16,500. Out of this total, 10,000 transits to and from the Americas (T_{AM}=10,000), broken out by (T_A=4,000) Trans-Atlantic crossings and (T_P=6,000) Trans-Pacific crossings. We focus on the subset of crossings to and from the Americas because a substantial portion of each of these transits falls within the GOES coverage area, as seen in Figure 3. Because we are using very conservative factors in this case study, we did not further reduce the number of transits to account for the proportion of the transit routes that fall within the GOES coverage area.

Figure 3. GOES Coverage Area

As discussed in the text leading up to Table 1, the cases of cargo loss that actually get reported are very small. In reality, it is estimated that over 10,000 cargo containers worldwide are lost overboard each year [Posada], [Storandt]. The proportion of containership transits traveling to or from the Americas each year is $T_{AM}/16{,}500 = 0.61$. Based on this proportion and the assumption that the cargo containers lost overboard are spread evenly among all major transit routes listed in Table 2, we make the assumption that roughly 61 percent of these lost containers are lost during transits to and from the Americas. Thus, a conservative estimate of the number of cargo containers lost from ships transiting to and from the Americas each year is

$$TEU_{LOST} = 0.61 * 10{,}000 = 6{,}100 \text{ TEU}$$

Containerized cargo is valuable and can range from thousands to hundreds of thousands of dollars per container. In the report titled *Marine Terminal Productivity Measures,* TranSystems Corporation (2000) states that the average weight of cargo of 7.5 metric tons per TEU. The authors also state that, for general estimation purposes, the average value of containerized cargo is $2,650 per ton. In a separate report, the average value of containerized cargo is listed at $4,300 per metric ton [Smith]. For our purposes, we will conservatively assume a value of $3,000 per metric ton. Thus, the average containerized cargo value is7.5 metric tons/TEU * $3,000/metric ton = $22,500/TEUMultiplying the total number of containers lost (TEU_{LOST}) by the average value of each container provides an estimate of the total value of containerized cargo lost during transits to and from the Americas on an annual basis as

$$E_{TLV} = 6{,}100 * \$22{,}500 = \$137.3M$$

Finally, we compute the Estimated Preventable Container Losses due to Improved GOES-R (E_{PCL}) as

$$E_{PCL} = E_{TLV} * P_{LPG} * P_{LHW}$$

This computation is variable based on the uncertainty associated with the proportion of containers lost due to heavy weather (P_{LHW}=Y) and the proportion of that amount that is preventable due to GOES-R (P_{LPG}=X). We computed a sensitivity matrix by varying both X and Y from 1 percent to 50 percent (see Table 3). An example of how the matrix values are computed is shown below.

If we assume that 40 percent of the container losses are attributable to heavy weather, and of that amount, 20 percent could be prevented due to GOES-R, then the potential total value of preventable container losses is

$$E_{PCL} = \$137,300,000 * 0.4 * 0.2 = \$11.0M$$

Table 3. Benefits Sensitivity Analysis Based on Percentage of Containers Lost Due to Heavy Weather and Those Losses Preventable Due to GOES-R ($M 2003)

For this analysis we have conservatively assumed that 30 percent of the containers lost are due to heavy weather and 30 percent of that amount could be prevented using GOES-R data, resulting in an annual benefit of $12.4M (see computation above). Note that this computation of potential cost savings does not include the potential value of reduced damage to ships or deck equipment; or from reduced crew losses or injuries.

Transit-Time Savings for Container Ships

In order to obtain an estimate of the potential transit-time savings that a container ship might realize from improved ship routing one must begin by estimating the operating costs of such a ship. These costs can vary according to both the elements that are included in the calculation and the size of containership assumed for the calculation. The sources of operating costs researched for this report provide estimates of what could be considered “low,” “medium,” and “high” operating costs for a “typical” U.S. container vessel. These values are shown in Table 4.

Table 4. Operating Costs for Containerships (2003)

Data Source	Daily Op. Cost	Hourly Op. Cost (HOC)	Level
(Pritchett, undated)	$27,000	$1,125	Low
(Smith, 2000)	$44,000	$1,833	Medium
(Smith, 2000)	$56,500	$2,354	High

In his report titled *Benefits of NPOESS for Commercial Ship Routing—Transit-Time Savings*, Kite-Powell (2000) estimated the average savings for containerships from routing with and without National Polar-orbiting Operational Environmental Satellite System (NPOESS) data. For Atlantic transits, the average savings without NPOESS data is 4 hours per transit and with NPOESS data it is estimated to be 7 hours per transit for a difference of 3 hours. For Pacific transits, the average savings without NPOESS data is 12 hours and with NPOESS data it is estimated to be 21 hours for a difference of 9 hours. These savings of 3 and 9 hours are attributed to NPOESS working in concert with more traditional observations from the Polar-orbiting Operational Environmental Satellite (POES), the Defense Meteorological Satellite Program (DMSP), ground-based Doppler radar systems, airborne sounders and radar aircraft.

The author notes that while NPOESS, a polar orbiting satellite, is helpful for ship routing, he would expect that ship routing would likely benefit more from the frequent updates in the tropics and mid-latitudes provided by geostationary satellite coverage, such as GOES [Kite-Powell]. With this and the NPOESS baseline in mind we determine the range of potential transit-time savings due to GOES for both transatlantic and transpacific crossings.

In a similar fashion to the estimation of hourly operating costs for containerships, we assign values of (S_A = 1, 2, and 3 hours) for levels low, medium, and high, respectively, for possible Trans-Atlantic crossing savings. Likewise for Trans-Pacific crossing, we assign value of (S_P = 3, 6, and 9 hours) for low, medium, and high levels of savings. Finally we compute the total estimate of transit-time savings due to GOES as the sum of savings from Trans-Atlantic crossings and Trans-Pacific crossings as

$$E_{TTS} = (T_A * HOC * S_A) + (T_P * HOC * S_P)$$

This computation is variable based on the uncertainty associated with the vessel's operating cost (Y=HOC), and the uncertainty of the amount of hours saved due to GOES ($X=S_A$ or S_P). This calculation is to be completed in two steps. First we compute a benefits sensitivity matrix for the Trans-Atlantic crossings by varying X and Y through their defined ranges (see Table 5).

Table 5. Benefits Sensitivity Analysis for Trans-Atlantic Crossings Based on Range of Hours Saved and Vessel Operating Costs $M (2003)

Then we compute a benefits sensitivity matrix for the Trans-Pacific crossings by varying X and Y through their defined ranges (see Table 6).

Table 6. Benefits Sensitivity Analysis for Trans-Pacific Crossings Based on Range of Hours Saved and Vessel Operating Costs $M (2003)

The total range of benefits due to transit-time savings is ($24.8, $55.3). The low and high ends of the range are calculated by summing both Trans-Atlantic and Trans-Pacific (low, low) and (high, high) values, respectively. We conservatively estimate that the average annual total transit-time savings due to GOES are $80.7M, or, the sum of the (medium, medium) values for both Trans-Atlantic and Trans-Pacific crossings.

Finally, we compute the entire average annual benefit for commercial container shipping due to GOES-R as the sum of the cargo loss prevention and the transit-time savings:

$$E_{TOTAL} = E_{PCL} + E_{TTS} = \$12.4M + \$80.7M = \$93.1M$$

The Present Value (PV) of the sum of the benefits at a 7 percent discount rate for the period 2015 to 2029 is $403M. This computation of PV does not include a factor to account for the predicted continued growth in global container shipments. Including a growth factor over the lifetime of the GOES-R series would be somewhat speculative, but would significantly increase the calculated PV for this case study.

Case Study 2: GOES Contribution to U.S. Economy through Improvements in Fisheries Management

Overview

Fisheries managers depend on accurate location of fish to estimate their populations, a number critical in setting policies. Ocean environmental conditions play a significant role in fish behavior. Fish aggregation, migration and dispersal are affected ocean environmental conditions. Wind causes turbulence and mixing in ocean layers, which in turn, changes temperature and other conditions of the water, and influences vertical movement. Wind induced currents transport fish and nutrients [Laevastu]. Since fish behavior is directly linked to environmental conditions of the ocean, understanding these conditions as accurately as possible and taking this environmental information into consideration will reduce the error of population estimates. This will enable managers to set more accurate quotas that will protect the species while at the same time not place unnecessarily strict limits on commercial and recreational fishing.

Commercial and recreational fishing are significant contributors to the economy. The total value added[2] to the economy of commercial fishing was $28.4B in 2002 [NMFS, Fisheries of the United States, 2002-2003] and the economic impact of recreational fishing $35.6B in 2001, with approximately $9B attributed to saltwater fishing alone[3] [U.S. Fish and Wildlife Service, 2001]. Improving our knowledge of ocean environment and weather data would lead to better understanding of fish behavior and ocean weather forecasting, leading to better decisions with reduced uncertainty with likely economically beneficial results.

In addition to improvements in fisheries management, more accurate location of fish can also result in more efficient use of gear, fuel, and bait, leading to a reduction in overhead or operating costs without sacrificing results in catch. Finally, human dependence on commercial fishing and participation in salt-water recreational fishing often put life and property at risk. More accurate information on ocean environmental conditions would improve forecasts that could reduce at-sea losses.

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[2] Details of the methodology of this calculation are not included in this report (Fisheries of the United States 2002). As described in this report, "Value added is an economic term to express the difference between the value of goods and the cost of materials or supplies that are used in producing them. It is a measure of economic activity that eliminates the duplication inherent in the sales value figure that results from the use of products of some establishments as materials or services by others. Value added is thus defined as the gross receipts of a firm minus the cost of goods and services purchased from other firms. Value added includes wages, salaries, interest, depreciation, rent, taxes and profit."

[3] This $9B is a percent of the total based on the proportion of saltwater recreational fishing expenditures out of total expenditures from the ASA 2002 report. The U.S. Fisheries and Wildlife Service 2002 report does not stratify to this detail.

Methodology

The methodology used to develop estimates of benefits to fisheries related industries begins with building the case that environmental information plays a significant role in decisions made regarding fisheries management. More specifically, facts from published literature will be shown to support the case that:

- GOES is one of among many sources of ocean environmental information, in particular SST. It is expected that the ABI on GOES will have significant improvements over current GOES.
- Environmental data, such as SST, can improve the accuracy of the information used in fisheries decision-making, by providing a more complete understanding of fish behavior and therefore their location, leading to more accurate estimates of population sizes.
- These decisions are often made based on information of some uncertainty, and consequently very conservative restrictions are applied.
- More accurate information on fish populations would reduce the need to be overly conservative with fishing restrictions, thereby leading to a potential increase in the catch quotas of some species without harm to sustainability and may also provide more information regarding species for which we have little information.
- The commercial and recreational fishing industries have significant impact on the U.S. economy, and even a very small increase in the number of fish landed/caught has significant ripple effects throughout the economy.

Estimates for the benefit of GOES is assumed to be an increase in fish harvest, and will be estimated as a percent increase in the U.S. value to the economy of commercial and recreational fishing taken from published sources. A range of values will be shown and more detailed examples will be provided to show how these benefits could be achieved.

Uncertainty and Decisions in Fisheries Management

In 1996, the Sustainable Fisheries Act (SFA), amending the Magnuson-Stevens Fishery Conservation Management Act (MSA) of 1976, became law. The SFA included “more stringent requirements to rebuild overfished fisheries and manage against overfishing, and a greater recognition of essential fish habitat.” In addition, under the SFA, “Congress raised the overfishing standard by providing the mandate for the Councils to specify objective and measurable criteria and management measures to end overfishing and rebuild overfished stocks to levels consistent with producing the maximum sustainable yield (MSY) from each fishery.” [NMFS, April 2002].

The yearly report by the National Marine Fisheries Service (NMFS) on progress to address these issues describes the status of fish stocks managed in the U.S. Exclusive Economic Zone (EEZ), which extends to 200 miles offshore and covers more than 2 million square miles. Key status conditions are overfished (fishing mortality above threshold), overfishing (biomass below threshold) and approaching overfishing. In this report for 2001[NMFS, April 2002], 959 stocks were identified, 304 with known biomass status and 655 with unknown status.[4] Of the 655 stocks with unknown status in 2001, 120 are considered “major” (i.e., with landings over 200,000 pounds) and consequently, of more commercial value than minor stocks. Finally, in 2001, 81 stocks were found to be overfished, and 65 stocks as experiencing overfishing.

Based on estimates of population status, management actions, such as rebuilding programs, are put into place. According to the NMFS April 2002 report, *Toward Rebuilding America’s Marine Fisheries*, “Any stock that has previously been listed, or is currently listed, as overfished is required to have a rebuildling program until the stock has been rebuilt to levels that are consistent with supporting maximum sustainable yield (MSY) on a sustainable basis.” This report identified 74 rebuilding programs either currently implemented or approved, with 67 of these in effect for stock currently listed as overfished.

[4] Whereas these numbers for 2001 have risen since 1997, (with 727 stocks total identified, and 448 of unknown status) it is difficult to compare current with previous years since the definition of key criteria, such as overfished and overfishing, have changed (NMFS, 2001).

Commercial fisheries can be managed by “specifying the amount of harvesting allowed; the areas of fishing and times of the year that fishing can take place; the gear that can be used; minimum fish size limits; and in some cases, the amount of fish that any single fisher, community, company, or other entity can catch. Recreational fisheries more often impose minimum size limits, daily catch limits, seasons, and sometimes gear restrictions and requirements to release fish that are caught.” [National Research Council]

However, fisheries management actions are not always perceived to be fair to commercial and recreational fishers, and often result in lawsuits against NOAA Fisheries [NMFS, December 2002], [Southwick]. One reason that fishermen challenge fisheries management actions is that the determination of whether a stock is in a condition of overfishing is based on estimates of population that have a high degree of uncertainty. This is recognized in NOAA Fisheries Strategic Plan:

> “Recovery of protected species also depends upon reliable, precise estimates of their abundance…. This lack of data can increase the risk of depletion and extinction for protected species, or conversely, increase the probability that species will be misclassified under the Endangered Species Act … which can result in potentially significant losses to the nation. [NMFS, July 2003].

Primary input for status determination for most stocks is a “reliable estimate” of the weight (biomass) of a group of fish [Witherell]. The ocean is a vast area, and any snapshot of fish population based on surveys and catch reports extrapolated to achieve the total population estimate may be based on the best available information and science, but remains, nevertheless, subject to a great deal of uncertainty.

With perfect information on fish biomass, it would be expected that such management actions would have the anticipated benefits of protecting the species while providing fishermen with the greatest opportunity to harvest fish. Management actions would be more tolerated and accepted if harvesters could be shown that these estimates are as accurate as possible.

> “In an ideal world, accurate and precise estimates of the abundance of fish stocks and their dynamics (how and why population levels change) would be available to set sustainable harvest levels to accommodate commercial and recreations demand. In reality, fishery management is based on imperfect estimation of the number, biomass, productivity, and age structure of fish populations and incomplete knowledge of population dynamics.”[National Research Council]

Given this uncertainty, fisheries managers generally practice the “precautionary principle” in setting harvest restrictions [Thompson]. The main points of this principle relate to the following questions and responses.

> “What should be the relationship between intended catch targets and absolute catch limits? Answer: Intended target catches … should be well below the levels at which the stock’s long-term productive capacity might be jeopardized…. What should be the management response to a given level of uncertainty surrounding estimates of key population parameters? Answer: Greater uncertainty regarding a stock’s productivity should correspond to greater caution in setting the target catch rate.” [Thompson].

If it is true that fisheries management errs more on the side of caution with respect to setting catch target limits, this implies that, more often than otherwise, a larger buffer exists between the catch target and absolute catch limits which, by definition, is associated with the boundary of the danger zone, potentially jeopardizing the stock’s long-term productivity [Thompson]. This larger buffer provides an opportunity for benefits if fisheries management can reduce the error in biomass estimates, since this would mean that catch quotas could be raised for some species without harming sustainability.

Improving Fish Biomass Estimation

Fishery managers follow several steps in a stock assessment, which is then used to control catch to, ideally, produce the maximum sustainable yield, or long-term potential yield for each species. Critical to this process is the choice of data collection procedures and collection of data, which includes surveys to estimate biomass. Besides use of commercial and recreational catch numbers, surveys are used to estimate biomass. Survey methods include trawl, longline, pot or trap, mark-recapture and aerial techniques. Biomass data are then used in models, which take into account the life cycle of the species under consideration, to develop acceptable harvesting rates and strategies [National Research Council].

To date, using sea surface temperature as an input to estimating biomass is done only for sardines [Detlor]. Although there may not be a direct correlation between biomass and temperature for all other species, several studies have shown that temperature is among the most significant environmental factor influencing fish behavior. The reason this is so critical in fisheries management is that "it is important that surveys are conducted under similar environmental conditions, otherwise, differences in catch rate may reflect difference in spatial distribution instead of abundance." [Pichel]. In a National Resource Council report, among several of its findings is the recommendation that "…surveys offer the best opportunity for controlling sampling conditions over time and the best choice for achieving a reliable (abundance) index if they are designed well with respect to location, timing, sampling gear, and other considerations of statistically valid survey design." [National Research Council] More specifically, in order to interpret and compare survey results, environmental effects must be taken into consideration.

GOES Sea Surface Temperature (SST)

Among the ocean environmental parameters capable of being measured from remote sensors is SST. The advantage of satellite SST over ship and buoy measurements is the "global, nearly uniform coverage (except for clouds) with high spatial resolution (1 km)." [Wu]. Satellite SST is created from both the POES and GOES. It is expected that SST from the GOES imager (ABI) will be an improved product over what is obtained from the Advanced Very High Resolution Radiometer (AVHRR) on POES. This is due to higher spatial resolution, more frequent images of an area with the same viewing angle, better cloud and aerosol detection and less noisy data [Schmidt].

Quantifying Benefits to Commercial Fishing

Much economic data exist for specific fisheries, such as, for the Northeast fisheries [Georgianna] and for Alaskan fisheries [Hartman]. However, it is difficult to extrapolate from detailed costs for these specific fisheries to the entire U.S. Consequently, benefits to the economy due to GOES-R will be calculated as a potential percent increase in total U.S. landings (in weight), which will then be translated into dollars according to the total value added to the economy of commercial fishing calculated by the NMFS.

Facts from the previous section provide the basis for the reasonable assumption that with more accurate estimates of SST, and incorporation of this information in surveys to reduce the uncertainty of fish biomass estimates,[5] there is the potential to increase catch quotas of some species without impact to sustainability. Consequently, GOES-R is likely to have a positive impact on the commercial fishing industry in the U.S. What is uncertain is the degree of impact. Our methodology here will be to vary percents of impact and show an example of how these benefits could be realized.

As stated earlier, commercial fishing in the U.S. is estimated to have a value-added to the economy of approximately $28.4B in 2002.[6] We define benefits to the U.S. economy of increasing catch due to GOES-

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[5] A significant assumption is that GOES-R SST is available and used. The infrastructure required to facilitate use of this data is not part of this analysis.

[6] Total U.S. economic value added is stratified by economic sector, and includes the harvesting sector (which would be sales less the cost of goods and services used and/or consumed to catch fish, including such items as: fuel/oil, ice, crew groceries, dockage charges, bait, insurance and unloading.), primary and

R data as a function of total value added (inflated from 2002 to 2003 (inflated by 1.8 percent) to be $28.9B) as follows:

$\text{Benefit}_{GOES} = \text{EVCF}_{2003} \times P_{Bio} \times P_{GOES,,}$ where

> EVCF_{2003} = the calculated economic value, in 2003 dollars, of commercial fishing to the U.S. economy in 2002;
>
> P_{Bio} = the percent of EVCF_{2003} that represents the estimated potential increase in economic value attributed to increase landings as a result of more accurate biomass estimates;
>
> P_{GOES} = the percent attributed specifically to the contribution of improved sensor accuracy and increase in timeliness of GOES R.

Table 7 shows the results of varying these parameters from 1/10 of 1 percent to 10 percent of total valued added to the U.S. in 2003 dollars.

Table 7. Benefits to U.S. Economy from GOES-R Commercial Fishing $M (2003)

	P_{Bio}				
P_{GOES}	**10%**	**5%**	**1%**	**.5%**	**.1%**
10%	289.0	145.0	28.9	14.5	2.9
5%	145.0	72.3	14.5	7.2	1.5
1 %	28.9	14.5	2.9	1.5	.3
.5%	14.5	7.2	1.5	.7	.1
.1%	2.9	1.5	.3	.1	< .1

For the purposes of this analysis, we will use $3M per year (2003 dollars) to represent the benefits due to GOES-R.

Just as an example of how an increase of $3M to the U.S. economy might be realized, consider Alaska pollock. In 2002, pollock alone accounted for approximately 35 percent of all commercial fish landed in the U.S. (3.3B pounds out of a total 9.4B pounds). In addition to the largest landings, Alaska pollock was valued at $210M dollars, ranking 4th in overall value by species. Clearly Alaska pollock is a significant species in the U.S. [NMFS, September 2003].

Based on the U.S. value added calculation [NMFS, September 2003], roughly 9.4B pounds of landings contributed to a total value-added to the economy of at $28.9B (2003) results in an average of approximately $3 per pound. Therefore, a $3M per year increase could result from as little as 1M pound increase in landings (only about one-hundredth of 1 percent of current total landings). Alaska pollock, however, is a lower-value fish per pound, averaging around $.06 per pound, or just 2 percent of the average value at sales.[7] It is assumed, consequently, that 50 times as much pollock, or 50 million pounds, or just an increase of 2 percent in the 2002 pollock catch, would add $3M to the U.S. economy.[8] Again, this is just an example of how $3M could be realized, and does not take into account potential increases in other (perhaps higher-valued) catch.

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secondary wholesale and processing, and retail trade from food service (restaurants) and from stores. (NMFS, 2003).

[7] Average dollars per pound is based on the value of the sale of the catch. Value of sales of the 9.4 billion pounds of catch was $3.1B, so an average of $.33 per pound. (As an aside, shrimp, the highest value catch, had a sale value of $1.45 per pound.)

[8] As an aside of how much effort it takes to catch 5 million pounds of pollock, in a survey during a period of approximately 1 week in August 2000, 27 vessels spent 1,074 hours effort to conduct 167 hauls and retrieved approximately 6.3 million pounds of pollock. (Wilson).

Quantifying Benefits to Recreational Fishing

Similar to commercial fishing, recreational fishermen and the recreational fishing industry would benefit from more targeted fishery restrictions, which are viewed by recreational anglers as severely limiting their enjoyment of the sport. Numerous web sites are devoted to lobbying congress regarding fishing restrictions and the impacts to sport-fishermen [Savefish.com].

Recreational fishing in the U.S. has significant economic impact as mentioned earlier. Total recreational fishing (which includes freshwater, saltwater, and Great Lakes) expenditures in 2001, as estimated by the U.S. Fish and Wildlife Service, was $35.6B, and has been estimated to be as high as $116.1B.[9] We will use the more conservative number for this analysis.

For this benefit analysis, we will restrict the benefits to saltwater fishing activities since these are the fishermen affected by fishing restrictions. It is an assumption that these anglers will be affected by similar restrictions imposed on saltwater recreational fishing as the commercial fishing above.

The U.S. Fish and Wildlife Service 2001 report does not stratify expenditures by angler (for example, saltwater versus freshwater) but the American Sportfishing Association (ASA) report does. In that report, saltwater fishing expenditures represent approximately 25 percent of the total. Using that proportion on the U.S. Fish and Wildlife estimates from Table 1 would imply that expenditures related to recreational saltwater fishing is estimated at approximately $ 9B in 2001. Estimated total of marine recreational catch in 2001 was 440M fish, of which 57 percent were released. [NMFS, September 2002]. For this analysis, we assume that catch quotas apply only to those fish kept, so we assume that total value added to economy for fish caught is $3.9B.

Fishing attracts tourism and is a driving force in many areas of consumer spending. It is reasonable to assume that if fishing restrictions could be lessened without harm to the catch population, an increase in economic spending in this sector could be expected.

Benefits due to GOES-R to recreational anglers and the recreational fishing industry will be calculated in a similar fashion to benefits for commercial fishing. Using the estimate of $4.1B (2001 inflated to 2003) total economic impact of recreational saltwater fishing that could potentially increase with relaxation in fishing restrictions without harm to population. Therefore, the estimates are calculated using the following equation:

$Benefit_{GOES} = EVRF_{2003} \times P_{Bio} \times P_{GOES}$ where

> $EVRF_{2003}$ = the estimated value of saltwater recreational fishing to the U.S. economy for 2001 inflated to 2003
>
> P_{BIO} = percent of $EVRF_{2003}$ that represents the estimated potential increase in economic value attributed to fish biomass estimate accuracy improvements, and
>
> P_{GOES} = percent attributed specifically to the contribution of improved sensor accuracy and increase in timeliness to GOES-R

Table 8 shows the results of varying these parameters from 1/10 of 1 percent to 10 percent of total valued added to the U.S.

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[9] As stated in the ASA report: "The expenditures reported here are greater than those reported by the U.S. Fish and Wildlife Service. Sportsmen often attributed purchases to both fishing and hunting (especially vehicles and big-ticket items). These items were not included in the Service's fishing expenditure estimates. Such items were included above by prorating each item's cost based on each respondent's total days of hunting and fishing."

Table 8. Benefits to U.S. Economy from GOES-R Recreational Saltwater Fishing $M (2003)

P_{GOES}	P_{BIO}				
	10%	**5%**	**1%**	**.5%**	**.1%**
10%	94.0	47.0	9.4	4.7	.9
5%	47.0	23.5	4.7	2.4	.5
1%	9.4	4.7	.9	.5	.1
.5%	4.7	2.4	.5	.2	< .1
.1%	.9	.5	.1	< .1	< .1

For this benefits analysis, we use $M per year to represent the value added to the U.S. economy due to recreational saltwater fishing activity from improvements in GOES-R.

To better understand how these benefits could be realized, consider the number of saltwater anglers and their per day expenditures. In 2001, there were approximately 9 million saltwater anglers and an estimated 90 million fishing days, or approximately 10 days per angler per year [ASA]. Per angler expenditure per year of has been estimated at approximately $1000, or $100 per day. [United States Fish and Wildlife Service]. A $1M increase could easily be achieved with growth in participants (1000 per year or an increase of 1/100 of a percent) or an increase in one fishing day by 10,000 anglers (or 1/100 of a percent increase in current fishing days.)

Additional Benefits—Reduction in Operating Costs and Loss of Life and Property

Additional benefits from improved measurements from GOES-R could be realized as reduction in operating costs due to more efficient fish location and reduction of loss of life and property due to more accurate severe weather forecasts. These benefits are not quantified.

Vessels currently use many tools to locate fish as efficiently as possible. In addition to use of sonar and catch history, data on sea conditions and weather are important for the fisherman. SST maps are popular, identifying borders between cooler and warmer seas, and currents and eddies, because they can help fisherman locate fish populations more efficiently. Several companies supply SST images to fisherman for a fee [ROFFS]. Since per trip operating costs are a significant overhead, fishermen are highly motivated to use these data. Consequently, it is reasonable to assume that more accurate SST information could reduce fishing operating costs and benefit commercial fishing.

Fishing is the most hazardous occupation in the world. “Fishers face a risk of death on the job that is 20 to 30 times greater than any other single occupation.” For the period 1992 to 1996, the risk (for fishermen) was 140 per 100,000 workers versus only 5 per 100,000 for the entire workforce. [Bureau of Labor Statistics] Between 1994 and 1999, 57 percent of all fishing deaths resulted from vessel casualty. Between 1994 and 1998, 897 fishing vessels were lost in the United States. Total loss of vessel and deaths cost the fishing industry over $240M annually (1999). In addition, the cost to the Coast Guard for 8000 fishing vessel rescues, expending over 38,000 resource hours, cost $45.7M (1999) [Spitzer]. Although reductions in losses have occurred with safety measures, such as use of personal floatation devices, and education, better knowledge of sea state and severe weather has the potential to reduce some of these losses.

Conclusion

Conservative estimates of the annual benefits to fisheries management of improved SST measurements are $3M for commercial and $1M for recreational fisheries, for a total of $4M. Additional potential for benefits, although not estimated here, could result from a reduction in operations cost due to more efficient location of fish and reduction in loss of life and property from more accurate severe weather forecasts. The total NPV for the 15-year period of interest is $17M.

Case Study 3: Benefits Case for the U.S. Golf Industry from Improved Weather Forecast Accuracy

Overview

Golf is big business in the U.S. In 2001 there were nearly 16,000 regulation golf courses in the U.S. supporting 518M rounds of golf played by 37M domestic golfers. Moreover, the golf economy accounted for over $62B worth of goods and services in the U.S. in 2000. Roughly $39B came from golf's core industries, while the remainder came from golf-related expenditures made in indirect industries such as real estate, travel, and tourism [World Golf Foundation].

The golf industry is extremely dependent on accurate weather information to run the most efficient, cost-effective, and profitable operation possible while safely meeting the recreational demands of a large segment of the U.S. population. From individual golfers, to groundskeepers, golf retailers, operations managers and tournament planners, all facets of the industry rely on weather information to maximize operational efficiency and ensure player safety. Better forecasts or nowcasts from GOES-R could potentially benefit the golf industry in four areas: (1) golf safety, (2) irrigation efficiency, (3) grounds maintenance efficiency, and (4) tournament and personal golf planning. Not all weather related losses to the golf industry are avoidable. However, in each of these four areas, better forecasts or weather information could potentially result in actions that could reduce avoidabl*e* losses.

GOES-R sensors are expected to generate data that could provide for earlier and more accurate forecasts on convective weather (i.e., thunderstorms) and lightning conditions. As a result, facility managers can better anticipate when to close or evacuate courses to prevent player, spectator, or employee injury or death, and to avoid damage to courses and equipment. GOES-R data is also expected to contribute to more reliable forecasts of temperature, humidity, precipitation, and wind speed, so that grounds maintenance professionals can better time applications of herbicide, fertilizer, pesticides, and grass seed to avoid waste due to wash-off and spray drift. GOES-R data is also expected to contribute to more accurate estimates of water lost via evapotranspiration, which could lead to more efficient irrigation management by reducing unnecessary watering. Finally, more accurate and timely forecasts of convective weather in general, and precipitation and wind speeds in particular, could greatly assist tournament planners and individual golfers with their scheduling, thus avoiding unnecessary tournament, vacation or recreational golf cancellations and minimizing player and course delays.

To build a case for economic benefits to this industry from GOES-R, we interviewed participants from a number of different facets of the golf sector: grounds maintenance professionals, facility operations managers, tournament planners, golf suppliers, insurance companies, industry trade associations, industry consultants, industry forecasters, and value added resellers of weather information, among others.
In addition, relevant industry data was culled from a number of different sources. The primary sources were the Environmental Protection Agency (EPA), United States Geological Survey (USGS) and National Association of Regulatory Utility Commissioners (NARUC) which report data on water usage and water rates, the National Oceanic Atmospheric Administration (NOAA), National Severe Storms Lab (NSSL), and the National Weather Service (NWS) which report data on injuries, deaths, and damages from storms, the World Golf Foundation which provides rich information on all aspects of the golf economy, and Grounds Maintenance Magazine which provides data on grounds maintenance expenditures by sector.

Detailed research was also conducted via industry publications, seminars, conference presentations and research papers, and research by trade associations and their members.

The Economic Benefits Case for Improved Golf Safety and Reduced Property Damage

More accurate and timely GOES-R data from the ABI and HES on potential for formation of convective weather as well as data on lightning activity from the planned Lightning Mapper could help reduce the number of golf-related deaths and injuries from lightning, as well as reduce some of the avoidable costs from associated property damage. There has been a steady decline in the number of deaths, but an increase in the number of injuries due to lightning as reported to NWS for the period from 1959 to 1994. The decrease in the number of deaths is attributed by NWS to improved detection and forecasts of lightning conditions, improved medical care, and increased public understanding of the dangers of lightning. The increase in the number of injuries may be due to improved emergency medical care that converts what formerly would have been fatalities into survivals with injuries.

Estimated benefits of improved golf safety, particularly with the Lightning Mapper Sensor (LMS), are included as part of the overall LMS benefits discussed in Case 5**.**, which uses a model developed by Lincoln Lab [Weber].

The Economic Benefits Case for Improved Grounds Maintenance Efficiency

More accurate and timely forecasts of wind speed, convective weather, precipitation and humidity could benefit the grounds maintenance industry by reducing mistimed applications of fertilizer, grass seed, pesticides, herbicides, and fungicides. 2001 grounds care expenditures by U.S. golf courses alone totaled $1.6B, as detailed in Table 9 [Ground Maintenance Magazine]. Narrowing that figure down to just the items that may be impacted by GOES-R, such as direct fertilizer and chemical applications (shaded areas in Table 9) and excluding components such as equipment and landscape accessories, results in expenditures of $75M, or $787M when inflated to 2003 dollars.

Table 9. Grounds Maintenance Purchasing by Golf Courses Estimated Annual Expenditures, 2001

Equipment Category	Value of Expenditures (2001)
Equipment	$ 742,474,569
Irrigation Equipment	104,459,009
Landscape Accessories	36,151,927
De-icing/Anti-icing Agents	5,247,706
Engines	17,899,450
Fertilizers	219,725,505
Herbicides	110,494,679
Grass Seed	105,245,358
Fungicides	166,057,982
Fertilizer/Pesticide Combo	79,466,422
Insecticides	75,407,853
TOTAL	$1,662,630,460
TOTAL Relevant to GOES (in shaded area)	$ 756,397,799
Total Relevant to GOES in 2003 dollars	$ 786,897,153

According to regional golf association specialists [Walker, Whitcomb], in an average year 5 percent of these expenditures are wasted due to mistimed lawn care applications that could be avoided with better weather information. Moreover, according to the Mass Golf Association, an additional 1 percent is spent for grounds care directly related to damage from golf carts driving on wet turf/grounds. Thus, up to 6 percent of these costs, or $47.2M could be saved (avoided) with more timely and accurate weather information (Table 10). As a baseline for this benefits analysis, 50 percent of these avoidable costs ($23.6M annually) are assumed to be recoverable with GOES-R. However, simulations reflecting a range of alternative assumptions are included in Table 11.

Table 10. Potential Grounds Maintenance Cost Savings for Golf Courses (2003)

Benefit Area / Percent of Economic Activity	Estimate of Avoidable Losses (2003)
Mistimed application (5% of $786,897,153)	$39,344,858
Damage to turf (1% of $786,897,153)	7,868,972
Total	$47,213,829

Table 11. Benefits Scenarios: Percent Recoverable from GOES-R (2003)

Percent of Avoidable Costs	Estimate of savings due to GOES-R (2003)
10 %	$ 4,721,383
20%	$ 9,442,766
30%	$ 14,164,149
40%	$ 18,885,532
50%	$ 23,606,915
75%	$ 35,410,372

Finally, this component of the golf case likely presents a very conservative estimate of true benefits since it looks exclusively at savings related to decreased maintenance expenditures, but does not address the far more complex issues of environmental benefits from reduced run-off of grounds care chemicals.

The Economic Benefits Case for Improved Irrigation Efficiency

Golf course irrigation efficiency would also benefit from improved weather information using GOES-R data. Freshwater withdrawals in 1995 totaled 341B gallons per day (BGD)[U.S.GS], with 1.5 percent or 5.1 billion gallons per day targeted for golf courses [Irrigation Association].

Median monthly charges for water vary significantly, depending on capacity of the utility and customer, as shown in Table 12. Commercial customers (such as golf courses) purchasing water from the nation's largest water systems (the lowest cost per gallon and the more conservative estimate) were charged $9.74 per 1,000 cubic feet, the relevant unit of measure (1 cubic foot=7.48 gallons) in 1996$ (Table 12) [Raftelis]. Converting to gallons and 2003 dollars yields a median monthly commercial water rate of $0.00148 per gallon.

Table 12. Median Charge (per 1000 cubic feet) by Provider Capacity and Customer Class* (1996)

Customer Class (per 1000 cubic feet, or 7.480 gallons)	Systems Producing >75 MGD	Systems Producing 15 – 75 MGD	Systems Producing <15 MGD
Residential	$13.19	$14.64	$15.61
Commercial	$ 9.74	$10.62	$11.58
Industrial	$ 7.93	$ 8.75	$10.29

*These figures are averages based on monthly water bills.

Multiplying these figures as in Table 13, yields total golf course expenditures for freshwater of nearly $2.8B per year (2003).

Table 13. Golf Course Freshwater Use and Fee Calculations (2003)

Calculation Details	
Total U.S. freshwater withdrawals (in 1995) MGD	341,000
Golf course share of freshwater withdrawals (1.5% of total) MGD	5,115
Median commercial charge per gallon (2003$)	$0.00148
Daily cost of freshwater for golf course usage (millions of dollars)	$7.57
Annual cost of freshwater for golf course usage (x 365) (million 2003 dollars)	$2,763.05

Irrigation efficiency can be improved at least three ways (1) improved information on water requirements—how much water needs to be applied on a daily basis on each course, (2) improved application efficiency—such as increased use of drip irrigation and other flow controls, or (3) reducing the demand for water by converting from water-intensive landscapes to landscape plant species that can better tolerate dry conditions (xeriscaping). We focus in this analysis on the first option (improved information about soil moisture) because satellite data can contribute to this option. Also, options 2 and 3 are more expensive to implement or may require changes in golfers' tastes—or at least a willingness to tolerate less lush landscapes. Industry participants interviewed were unable or unwilling to assess what portion of the irrigation costs could be saved with more timely and accurate weather information driving more efficient irrigation schedules. However, assuming that just 5 percent, or 18.25 fewer days of watering could result from enhanced GOES-R weather forecasting capabilities (consistent with Phase 2 Agriculture Benefits Case [NOAA, 2002]), then $138M (2003) per year could be saved. Alternative savings assumptions are reflected in Table 14.

Table 14. Golf Course Irrigation Savings Scenarios

Golf Course Irrigation Savings	Dollar Value of Savings $M (2003)
1 day/year	$ 7.57
3 days/year	$ 22.71
3.65 days/year (1% savings)	$ 27.63
5 days/year	$ 37.85
18.25 days/year (5% savings)	$ 138.16

Once again, we believe this estimate is very conservative for a number of reasons including that it only accounts for the current value of the water saved, and only uses commercial water rates. If the conserved water winds up being consumed by residential customers, for whom water rates were 35 percent higher when the Raftelis Consulting study was done (1996), these benefits figures would increase. Likewise, if we undertook the complex exercise of valuing the amount of water conserved annually based on a scenario that included future increases in water demand or perhaps even water shortages that prompt price hikes, the benefits calculations would again be far higher.

The Economic Benefits Case for Improved Tournament and Personal Golf Planning

"Among golf courses reporting a decrease in rounds played from 2000 to 2001, 52 percent cited weather as the leading reason." [World Golf Foundation] More accurate and timely forecasts of wind speed, convective weather, and precipitation could benefit tournament planners as well as recreational golfers by reducing costs associated with weather-related cancellation of tournaments and personal play, as well as allow for more efficient scheduling of tournaments and recreational golf.

Spending on golf tournaments and personal golf generate enormous revenues each year. In 2000, major golf tournaments and golf-related charity revenues totaled nearly $4.8B. At the same time, personal golf travel-related expenditures were a staggering $13.9B, while direct golf facility revenues (excluding tournament related numbers already cited) totaled another $13.3B. Finally, consumer spending on golfer supplies (equipment, apparel, magazines, books) was nearly $6.4B (Table 15), 50 percent of which were made at golf facilities according to industry pros [World Golf Foundation].

Table 15. Golf Tournament, Personal Golf, and Golf Facility Related Revenue in 2000 $M (2003) [World Golf Foundation]

Revenue Category	2000 Revenues $M (2003)*	
Golf-related tournament and charity revenues	4,796.01	
Major tournaments – direct**		927.06
Charitable fundraising tournaments		3,405.95
Tournament-related travel expenditures		463.00
Personal golf travel-related expenditures	13,883.50	
Lodging		5,414.40
Transportation		4,164.84
Food		2,776.91
Entertainment		1,527.36
Golf facility revenues***	13,290.01	
Golf courses (non-resort)		18,470.89
Resort facilities		2,294.76
Less membership dues/fees (approx. 36%)		(7,475.63)
ProShop consumer spending on golfer supplies (50% of total)	3,183.50	
Equipment		4,359.62
Apparel		1,052.65
Magazines		784.43
Books		170.30
Total	$35,153.02	

*Totals may not add due to rounding.
**Mutually exclusive. Revenues accruing to golf courses are in Major tournaments, and portion going to charity is in Charitable
*** Includes greens fees, equipment rentals, and food/beverage. Excludes membership dues/fees.

Each of these numbers is relevant to the benefits case since some portion of each is impacted by weather conditions. Tournaments can be delayed or cancelled completely in the face of severe weather while recreational golfers reassess and sometimes cancel their play if bad weather is forecasted. When weather forecasts miss the mark, golfers, charities, courses, airlines, hotels, restaurants, and pro shops, among others, can all be adversely impacted.

According to industry interviews, roughly 1 percent of U.S. golf tournaments are cancelled in a year due to weather, while weather-related recreational golf cancellations are estimated at closer to 5 percent [Davis], [Shepherd], [Walker], [Whitcomb]. The rate for recreational golf (golf facility revenues) tends to be higher, since the planning and revenues associated with tournaments make them far more difficult to cancel than a morning game of recreational golf. Recreational golf is much more susceptible to earlier reports of inclement weather than tournaments, which often wait until the day of an event or hours prior to the event to cancel. Industry interviews also indicated that cancellation rates for personal golf with travel (vacation expenditures) are estimated to be roughly 3 percent—lower than for recreational golf, yet higher than for tournaments. This, since the planning that goes into a golf vacation is far more significant than that associated with a regular local round, but far less involved than tournament planning. An estimate of the impact of weather-related cancellations on pro shop spending was also roughly 3 percent. Combined, these rates imply total lost revenue due to weather-related golf cancellations of $1.2B (2003) (Table 16).

Table 16. Summary of Lost Revenue Due to Weather Related Golf Cancellations $M (2003)

Revenue Category	Lost Revenue $M (2003)
Tournaments (1% of total)	$ 48.0
Personal golf vacations/travel (3% of total)	416.51
Golf facility revenues (5% of total)	664.50
ProShop consumer spending (3% of total)	95.50
Total lost revenue from golf cancellations due to weather	$ 1,224.50

Despite higher estimates from some in the industry, this case assumes a very conservative 2 percent or $24.5M (2003) of this lost revenue is recoverable as a result of GOES-R weather data improvements. Alternative impact scenarios follow in Table 17.

Table 17. Annual Reduction in Cancellations due to Improved Weather Information from GOES-R $M (2003)

Percent of Total Lost Revenue Avoidable due to GOES-R	Resulting Estimate of Annual Losses Avoided $M (2003)
1 %	$ 12.24
2 %	$ 24.49
5 %	$ 61.22
10 %	$ 122.45
20 %	$ 244.89

Summary: U.S. Golf Industry Benefits from Improved Weather Forecast Accuracy

Based on these assumptions, benefits to the U.S. golf industry from improved weather forecast accuracy could total over $186M per year (2003), with a net present value of $806M when benefits are calculated over the 2015-2029 period using a 7 percent discount rate (Table 18).

Table 18. Golf Related Savings from Improved Weather Forecast Accuracy

Benefit Area	Estimate of Annual Savings due to GOES-R $M (2003)
Safety (lightning deaths/injuries/property damage)	0*
Ground maintenance	$ 23.61
Irrigation	$ 138.16
Tournament/personal play scheduling/planning	$ 24.49
Total annual savings	$ 186.26
NPV of total (2015-2029)	$ 805.97

*Included as part of the total lightning safety benefits due to a LMS documented in Case 5.

Finally, for reasons previously indicated, this is likely a conservative benefits estimate. Indeed, using a higher expected future valuation for scarce water resources and including the environmental value of reducing chemical run-off from lawn care applications would undoubtedly increase these golf benefits estimates considerably. Both areas should be focuses of future study.

Case Study 4: Benefits Case for the U.S. Landscaping Industry (Non-Golf) from Improved Weather Forecast Accuracy

Overview

By any measure, the U.S. landscaping/grounds maintenance industry is sizeable. The revenue for the landscaping industry in 2002 was approximately $52B. This includes landscape construction/build, landscape maintenance, irrigation installation and repairs, landscape lighting, water features, power equipment, nursery supplies, fertilizer, chemicals, etc. [IGIN]. Alternatively, the 60,000+ base of subscribers to Landscape Management Magazine alone generate $48.2B annually in revenues, have operating budgets of $39.3B and spend $6.1B annually on products and services [Landscape Management]. Finally, more specifically, "turfgrass as an industry is considered to well exceed the $25B mark." [PLCAA]. It is estimated that more than 500,000 people make their living directly from the care and maintenance of turfgrass across the country. The sale of lawn care products is estimated to total more than $4B a year, which represents nearly one-third of all money spent on gardening in the country. These figures have been on the rise for the past several years and are expected to continue a steady climb." [PLCAA].

Across all segments, the landscaping industry is extremely dependent on accurate weather information to run the most environmentally sound, efficient, and cost-effective operation possible. From independent landscaping businesses, to corporate facility managers and municipal parks commissioners, many facets of the industry rely on weather information to maximize operational efficiency and environmental safety. Better forecasts or nowcasts from GOES-R could potentially benefit the landscaping industry in two areas: irrigation efficiency and grounds maintenance efficiency. Not all weather related losses to the landscape industry are avoidable. However, in each area, better forecasts or weather information could potentially result in actions that could reduce avoidable losses.

GOES-R data is expected to contribute to more reliable forecasts of temperature, humidity, precipitation, and wind speed, so that grounds maintenance professionals can better time applications of herbicide, fertilizer, pesticides, and grass seed to avoid waste due to wash-off and spray drift. GOES-R data is also expected to contribute to more accurate estimates of water lost via evapotranspiration, which could lead to more efficient irrigation management by reducing unnecessary watering.

To build a case for economic benefits to this industry from GOES-R, participants from segments of the landscaping and golf grounds maintenance sector were contacted: grounds maintenance and landscaping professionals, facility operations managers, industry trade associations, industry consultants, industry forecasters, academic researchers, and value added resellers of weather information, among others.

In addition, relevant industry data was culled from a number of different sources. The primary sources were the EPA, USGS, and NARUC, which report data on water usage and water rates, and Grounds Maintenance Magazine, which provides data on grounds maintenance expenditures by sector. Detailed research was also conducted via industry publications, seminars, conference presentations and research papers.

The Economic Benefits Case for Improved Grounds Maintenance Efficiency

One segment of landscaping that offers the potential for significant benefits from enhanced weather information is maintenance. Specifically, more accurate and timely forecasts of wind speed, convective weather, precipitation, and humidity would help landscapers and grounds maintenance professionals reduce mistimed applications of fertilizer, grass seed, pesticides, herbicides, insecticides, and fungicides.

2001 grounds care expenditures by the U.S. landscaping industry (all grounds maintenance excluding maintenance of golf facilities) totaled $2.47B [Grounds Maintenance Magazine] as detailed in Table 19. Narrowing that figure down to just the items that may be impacted by GOES-R such as direct fertilizer and chemical applications (excluding components such as equipment and landscape accessories) results in relevant expenditures of $771M, or $802M when inflated to 2003 dollars.

Table 19. Non-Golf Landscaping Purchasing Estimated Annual Expenditures in 2001 (2001)

Equipment Category	Value of Expenditures (2001)
Equipment	$ 1,399,925,323
Irrigation Equipment	75,011,570
Landscape Accessories	114,719,179
De-icing/Anti-icing Agents	69,990,749
Engines	34,103,065
Fertilizers	284,394,922
Herbicides	174,875,450
Grass Seed	125,921,514
Fungicides	49,991,577
Fertilizer/Pesticide Combo	100,095,279
Insecticides	35,999,239
TOTAL	$ 2,465,027,867
TOTAL Relevant to GOES (in shaded area)	$ 771,277,981
Total Relevant to GOES in 2003 dollars	$ 802,377,331

According to regional golf association specialists, in an average year 5 percent of expenditures by golf maintenance professionals (who are critically focused on minimizing costs) are wasted due to mistimed lawn care applications that could be avoided with better weather information [Walker], [Whitcomb]. These sources estimated that wasted applications were even higher in the broader grounds maintenance industry. However, for the purposes of this benefits case, we will utilize the more conservative golf maintenance waste figure of 5 percent. Moreover, an additional 1 percent is spent for grounds care directly related to damage from use while the land is wet or saturated [Whitcomb]. Thus, up to 6 percent of these expenditures, or $48.1M (2003) could be saved with more timely and accurate weather information (Table 20). As a baseline for this benefits analysis, 50 percent of these costs savings ($24M annually) are assumed to be recoverable with better weather data from GOES-R. However, simulations reflecting a range of alternative assumptions are included in Table 21.

Table 20. Potential Grounds Maintenance Cost Savings for Non-Golf Landscaping (2003)

Benefit Area / Percent of Economic Activity	**Estimate of Avoidable Losses (2003)**
Mistimed application (5% of $802,377,331)	$40,118,867
Damage to grounds (1% of $802,377,331)	8,023,772
Total	$48,142,640

Table 21. Landscaping Benefits Scenarios: Percent Recoverable from GOES-R (2003)

Percent Losses Avoided	**Resulting Benefits Due to GOES-R (2003)**
10%	$4,814,264
20%	$9,628,528
30%	$14,442,792
40%	$19,257,056
50%	$24,071,320
75%	$36,106,980

Overall, this component of the landscaping case likely presents a very conservative estimate of true benefits since it looks exclusively at savings related to decreased maintenance expenditures, but does not address the far more complex issues of environmental benefits from reduced run-off of grounds care chemicals.

The Economic Benefits Case for Improved Irrigation Efficiency

Landscape irrigation efficiency would also benefit from improved weather information using GOES-R data. Freshwater withdrawals in 1995 totaled 341B gallons per day (BGD), with 2.9 percent or 9.9BGD targeted for landscaping [USGS].

Median monthly rates for commercial customers of the nation's largest water systems were $9.74 per 1,000 cubic feet, the relevant unit of measure (1 cubic foot=7.48 gallons) in 1996 dollars. Table 22 shows the wide range of per gallon charges, depending on customer and capacity of provider. Since usage was predominately commercial, that rate was selected for this analysis. Converting to gallons and 2003 dollars yields a median monthly commercial water rate of $0.00148 per gallon.

Table 22. Median Monthly Water Bills by System Size and Customer Class (1996) [Raftelis]

Customer Class (per 1000 cubic feet, or 7.480 gallons)	**Systems Producing >75 MGD**	**Systems Producing 15 – 75 MGD**	**Systems Producing <15 MGD**
Residential	$13.19	$14.64	$15.61
Commercial	$ 9.74	$10.62	$11.58
Industrial	$ 7.93	$ 8.75	$10.29

Multiplying these figures as in Table 23, yields total landscaping expenditures (excluding golf) for fresh water of over $5.3B per year (2003).

Table 23. Non-Golf Landscaping Freshwater Use and Fee Calculations (2003)

Calculation Details	
Total U.S. freshwater withdrawals (in 1995) MGD	341,000
Non-golf landscaping share of freshwater withdrawals (2.9 % of total) MGD	9,889
Median commercial charge per gallon	$0.00148
Daily cost of freshwater for non-golf landscaping $M	$14.64
Annual cost of freshwater for non-golf landscaping (x 365) $M (2003)	$5,342.04

Irrigation efficiency can be improved at least three ways (1) improved information on water requirements—how much water needs to be applied on a daily basis on each course, (2) improved application efficiency—such as increased use of drip irrigation and other flow controls, or (3) reducing the demand for water by converting from water-intensive landscapes to landscape plant species that can better tolerate dry conditions (xeriscaping). We focus in this analysis on the first option (improved information about soil moisture) because satellite data can contribute to this option. Also, options 2 and 3 are more expensive to implement or may require changes in customer tastes—or at least a willingness to tolerate less lush landscapes.

Industry participants interviewed were unable or unwilling to assess what portion of these costs could be saved with more timely and accurate weather information driving more efficient irrigation schedules. However, assuming that just 5 percent, or 18.25 fewer days of watering could result from enhanced GOES-R weather forecasting capabilities (consistent with Phase 2 Agriculture Benefits [NOAA, 2002]), over $267M per year could be saved. Alternative savings assumptions are reflected in Table 24.

Table 24. Non-Golf Landscape Irrigation Savings Scenarios $M (2003)

Non-Golf Landscape Irrigation Savings	Dollar Value of Savings $M (2003)
1 day/year	$ 14.64
3 days/year	$ 43.91
3.65 days/year (1% savings)	$ 53.42
5 days/year	$ 73.18
18.25 days/year (5% savings)	$ 267.10

Once again, we believe this estimate is very conservative for a number of reasons including that it only accounts for the current value of the water saved, and only uses commercial water rates. If the conserved water winds up being consumed by residential customers, for whom water rates were 35 percent higher when the Raftelis Consulting study was done (1996), these benefits figures would increase. Likewise, if we undertook the complex exercise of valuing the amount of water conserved annually based on a scenario that included future increases in water demand or perhaps even water shortages that prompt price hikes, the benefits calculations would again be far higher.

Summary: U.S. Landscape Industry Benefits from Improved Weather Forecast Accuracy

Based on these assumptions, benefits to the U.S. landscaping industry from improved weather forecast accuracy could total $291M per year, with a net present value of nearly $1.3B when benefits are calculated over the 2015-2029 period using a 7 percent discount rate (Table 25).

Table 25. Non-Golf Landscape Related Savings from Improved Weather Forecast Accuracy $M (2003)

Benefit Area	Estimate of Annual Savings due to GOES-R $M (2003)
Grounds maintenance	$ 24.07
Irrigation	$ 267.10
Total annual savings	$ 291.17
NPV of total (2015-2029)	$1,260

Finally, for reasons previously indicated, this is likely a conservative benefits estimate. Using a higher expected future valuation for scarce water resources and including the environmental value of reducing chemical run-off from lawn care applications would undoubtedly increase these landscaping benefits estimates considerably. Both areas should be focuses of future study.

Case Study 5. Benefits Case from LMS-Related Improved Lightning Forecast Accuracy

Overview

By any measure, lightning takes a significant toll each year on the U.S. economy, claiming numerous victims and imposing significant costs on an array of industries. From recreation and tourism to utilities and aviation, many industries rely on accurate and timely weather information to maximize safety and operational efficiency. NOAA's recent decision to include a LMS in the GOES-R satellite instrumentation could offer substantial economic benefits related to: improved lead time and/or reliability of warnings for thunderstorm winds/hail/flash floods and for tornadoes; improved information for commercial airlines on hazardous convective weather; and more reliable warnings of lightning ground strike hazards. This analysis will focus exclusively on the latter, assessing incremental economic benefits associated with more reliable warnings of lightning ground strike hazards and enhanced decision making capability beyond that achievable with current operational sensors [Weber]. Phase 1 and 2 GOES-R research has already focused on the other potential benefits areas.

According to research by Lincoln Lab, the LMS recently included in the specification for the NOAA GOES-R would help reduce human fatalities, injuries, and avoidable property damage by providing continuous, real-time surveillance of total lightning activity over large portions of the North and South American continents and surrounding oceans. In contrast to the current National Lightning Detection Network (NLDN), LMS would monitor <u>total</u> lightning activity, including the dominant intracloud (IC) component that is estimated to occur with order-of-magnitude greater frequency than cloud-to-ground lightning. IC lightning may occur 10 minutes or more in advance of a storm's first ground flash.[10] Thus, possible operational benefits of LMS include a reduced toll from cloud-to-ground lightning strikes owing to more reliable identification of electrically active storms [Weber].

It should be noted that since the infrastructure is not in place to realize benefits of even the current NLDN, current annual casualties are not attributed to the NLDN, but rather a "No Warning" system where individuals rely solely on "eyes and ears" to determine and respond to lightning threats.

To build a case for economic benefits related to the GOES-R LMS, a detailed literature search was conducted via industry publications, seminars, conference presentations and research papers, Internet articles/reports, academic organizations, and trade associations. In addition, interviews were done with convective weather and lightning experts at NOAA, NESDIS, and the National Severe Storms Lab. And relevant industry data was culled from a number of different sources including NOAA, National Weather Service, Storm Data, National Severe Storms Lab, Colorado Lightning Resource Center, and National Lightning Safety Institute. Ultimately, however, this analysis draws heavily from a study done for NOAA in 1998 by Lincoln Laboratory entitled "An Assessment of the Operational Utility of a GOES Lightning Mapping Sensor". Much of the following quantitative analysis represents an update of selected benefits estimates calculated in that report.

Lightning's Impacts

Cloud-to-ground lightning strikes take a significant toll, claiming numerous victims and imposing significant costs on the economy each year. In the United States, there are an estimated 25 million cloud-to-ground lightning flashes each year [NOAA, Lightning Safety, Overview]. While lightning can be fascinating to watch, it is also extremely dangerous. According to NOAA, lightning has been the second largest storm killer in the U.S. for the last 40 years, exceeded only by floods [NOAA, Lightning Safety, Medical]. The NWS shows an average 73 *reported* lightning fatalities per year during the past 30 years in their *Storm Data* publication. However, because lightning usually claims only one or two victims at a time, and because lightning does not cause the mass destruction left in the wake of tornadoes or hurricanes, lightning generally receives much less attention than the more destructive weather-related killers [NOAA, Lightning Safety, Overview].

Fortunately, according to statistics from Storm Data, deaths, injuries, and property damage from lightning have been on the decline in recent years as more sophisticated equipment, forecast techniques, and awareness campaigns have increased the accuracy and effectiveness of NWS storm warnings and watches. The impacts are noticeable. For the most recent 5-year period, 1998-2002, lightning has caused an average of 47 deaths, 303 injuries, and $39.5 million in damages per year, a welcome reduction from 30 year average fatality rate of 73 deaths [NWS, Office of Climate, Water, and Weather Services]. New weather satellites that include a LMS will presumably prompt further decreases in lightning casualties and avoidable damage.

While improving, the NWS figures are nonetheless thought to be underreported. Based on lightning research in Colorado, the NWS data likely underestimates deaths by roughly 30 percent and injuries requiring hospitalization by about 42 percent [Lopez, 1993]. Further research found that damage figures in STORM DATA were grossly underreported—damage of $27M in STORM DATA was estimated to be more like $330M [Holle, 1996]. Applying these factors, the 30-year average number of deaths from lightning annually may be closer to 95, with most recent 5-year averages of 61 deaths, 430 injuries, and $483M in property damage[11].

Moreover, further Colorado research [Cherington] indicates that for every lightning related death there are 10 lightning injuries that leave victims with various degrees of disability. Thus, while documented lightning injuries in the United States average about 300 per year, undocumented injuries caused by lightning are probably closer to 2 times that amount. For the purpose of this benefits analysis, the "Adjusted 5-year Average" figures in Table 26 will be used to calculate cost avoidance.

[11] It should be pointed out that some references have estimated total property damage in the U.S. due to lightning as between $5B and $6B annually [Walsh], roughly 10-fold increase from the source cited in the Lincoln Lab report, which was used for this analysis, only updated to reflect more recent data.

Table 26. Annual Lightning Statistics from Storm Data, with Adjustment Factors From Lightning Research

	Fatalities	Injuries	Property Damage
Storm Data 5-year Averages	47	303	$39.5 M (1996)
Adjustment Factors (from research)	1.3	1.42	12.22
Adjusted 5-year Averages	61	430	$483 M (1996)
Dollars Adjusted to 2003			$511M (2003)

While the analysis performed by Lincoln Lab in 1998 did not include a benefits assessment related to avoidable property damage, the analysis here will, albeit very conservatively. As stated in that report:

> "Clearly, much lightning-induced property damage (fire, building damage, tree damage) would not be avertable through better short term lightning warnings. Some reduction in power-surge induced damage to electronic equipment might be anticipated, however. Although most large, vulnerable Government and commercial sector facilities are protected by stand-by generators, these may not always be turned on early enough to eliminate the threat. Discussions with consumer computer repair personnel indicated that widely used surge protectors are effective in protecting against most power spikes, and that prevention of damage in the event of large spikes caused by nearby lightning would require disconnection of power cords and modems. Provision of reliable warnings of lightning threat might induce a fraction of owners to disconnect their computers during the storm. Although we were not able to obtain an estimate of the yearly costs of potentially avertable lightning strike damage to electronic equipment, we acknowledge that the total might be significant, given that such equipment is ubiquitous in our society.
>
> Our subsequent evaluation estimates the potential benefit of preventing fatalities and injuries through the provision of more timely lightning warnings. We note that the benefit evaluation methodology we use would apply to property damage as well, should avertable damage subsequently be found to comprise a significant total." [Weber].

In their discussion of the technical basis for LMS benefits, the Lincoln Lab report sets forth the following:

- The median of the distribution of the delay between the first intracloud and first cloud-to-ground flash in FL thunderstorms is about 6 minutes (analysis performed as part of the LISDAD effort);
- Intracloud to cloud-to-ground ratios of 10:1 are typical;
- Since current systems presumably generate reliable ground strike warnings for "line storms," the incremental benefit for them from LMS is small;
- Benefits are highest in storms where a large part of the overall ground strike exposure occurs during the developing phase of the storm, such as in air mass or "pulse" thunderstorms;
- LMS' incremental benefits hinge on providing warnings only a few minutes earlier than might otherwise be possible;
- A major dependency for realizing any benefit is the warning infrastructure required to rapidly alert people to the lightning threat.

Then, Lincoln Lab constructs their LMS Ground Strike Warning Benefit Model based on the following assumption/data:

- The model assumes the threat is of a constant level for a period of 20 minutes (typical duration for relevant portions of both a line storm and for an air mass thunderstorm).
- When individuals become convinced of a threat, they act to reduce the probability of a strike.
- Assumes that on average, people involved in recreation require significant time (10 minutes) to reach shelter and that a constant residual level of exposure remains (0.25 of their initial exposure). This includes golfers, hikers, boaters, etc. who all require time to move to shelter or shore.
- On average, people at work have buildings or vehicles nearby for shelter, thus reducing risk to negligible levels by 2 minutes after the time the threat is perceived.

- Assumes 3 warning levels with warning time assumptions based on flash detection and system integration time analysis: Level 1 relies on individuals eyes and ears, which is the mechanism of alert which is assumed for all current casualties; Level 2 assumes an automated, real-time lightning warning system has been put in place using **existing** sensors (WSR-88D and NLDN), and; Level 3 assumes a real-time lightning warning system based on LMS. (Note that both Levels 2 and 3 are theoretical in that the infrastructure to deliver this information in a timely fashion is not widely used even with today's sensors.) In Level 1, individuals are assumed to hear a line storm coming 15 minutes in advance, and take 10 minutes to respond to it as a real threat, while air mass storms assume that 5 minutes are required following the first proximate ground strike for the person to perceive a real threat and respond. Warning Levels 2 and 3 improve upon Level 1's "no warning system" baseline by using real-time sensor warnings (Table 27). The most significant improvement is in Level 3, where the LMS system is assumed to move the warning time for air mass thunderstorms 4 minutes prior to the first ground flash, 9 minutes sooner than a scenario with no warning system.

Table 27. Lightning Warning Time Relative to Beginning of Threat Period

Level	Line Storm	Air Mass
1. No warning system	-5 minutes	5 minutes
2. Real-time warning system – no new sensors	-10 minutes	2 minutes
3. Real-time warning system - LMS	-10 minutes	-4 minutes

Some of the key Lincoln Lab study findings that we will use here to calculate benefits are that:

- 41 percent of current casualties occurred during "infrequent" lightning (defined as an average cloud-to-ground rate of less than 1 per 4 minutes), are assumed to be the result of "bolts from the blue" and are unavoidable [Holle, 1993].
- Based on previous research the rates for the activities of victims at the time of the strike were 55 percent involved in recreation, 45 percent in employment related activities [Holle, 1993], [Lopez, 1995].
- A study of the relative frequency of "line" vs. "air mass" thunderstorms revealed roughly 55 percent of U.S. cloud-to-ground lightning exposure occurs in association with line thunderstorms and 45 percent related to air mass storms.
- Assumes "common sense" avoidance actions by individuals today alleviates the line-storm related threat for individuals at a job site who can move quickly to shelter. Consequently, for the remaining avoidable fatalities, the 45 percent in employment related activities are solely attributed to air mass storms and there are no fatalities for employment activities due to line storms.

We use these above assumptions to divide the 61 fatalities by activity and by storm type since the marginal improvement (reduction of death) under the scenario of a warning system with today's sensors and a warning system with a LMS vary by activity and storm type. Table 28 first calculates the estimated number of annual fatalities under a NO WARNING scenario (i.e., current) for each category using the Lincoln Lab findings.

Table 28. Calculation of Annual Lightning Fatalities by Activity by Storm Type

Adjusted Estimate of Annual Lightning Casualties 61	Bolt from Blue – Unavoidable 41% of 61 = 25	Avoidable 61 – 25 = 36		
		Employment Activity 45% of 36 = 16	Recreation Activity 55% of 36 = 20	
		Due to Air Mass Storms 16	Due to Air Mass Storms 45% of 20 = 9	Due to Line Storms 55% of 20 = 11

Estimates of the fatalities that would be expected under the two scenarios of warning system will be calculated as a fraction of current casualties resulting from no warning system (only eyes and ears). Lincoln Lab estimates[12] of these fractional reductions will be used and they are summarized in Table 29. Notice that the greatest expected reductions in casualties are for fatalities resulting from air mass storms, and in particular, those engaged in employment activities and assumed to be near shelter.

Table 29. Fraction of "No Warning" Scenario Fatalities Assuming Theoretical Warning Systems with Current Sensors and with LMS, by Activity by Storm Type*

Warning System Scenario	Air Mass - Employment	Line Storm- Recreation	Air Mass - Recreation
Real-time warning system – Current sensors	50 %	83 %	81 %
Real-time warning system - LMS	0 (i.e., no casualties expected)	83 %	50 %

*Based on analyses performed by Lincoln Labs [Weber].

Using the reduction ratios in Table 29, and the current annual fatalities by activity by storm type from Table 28, the expected casualties can be calculated for the two scenarios (Table 30). Notice in the final column that the resulting overall reductions are: 80 percent expected reduction in current casualties for a warning system with no new sensors, and a 61 percent expected reduction in a warning system using an LMS. These ratios are used to calculate the expected injuries (since we assume that avoidable injuries would mirror the activity and storm type differences as for fatalities) and property damage (assuming that only 10 percent of the total in Table 26, or $51.1M, would represent property for which avoidable actions can be taken) for the two warning scenarios. The resulting calculations appear in Table 31.

[12] The ratios in Table 29 have been simplified for this CBA but are based on the analyses performed by Lincoln Labs [Weber]. This CBA does not consider a No Avoidance Case so therefore all ratios are against the No Warning System scenario, in this case representing today's system in place resulting in an average of 61 casualties per year.

Table 30. Annual Lightning Fatalities vs. Warning Scenario

Warning Scenario	Bolts from Blue	Air Mass - Employment	Line Storm-Recreation	Air Mass - Recreation	Total	Resulting Reduction Ration (relative to Current Casualties)
No warning system Current	25	16	11	9	61	-
Real-time warning system – No new sensors	25	8	9	7	49	49/61 = 80%
Real-time warning system - LMS	25	0	9	5	37	37/61 = 61%

Table 31. Expected Fatalities, Injuries and Property Damages: Current vs. Realtime Warning System Scenarios $M (2003)

Warning Scenario	Fatalities	Injuries	Property Damage
No warning system Current	61	430	51.1
Real-time warning system – No new sensors	49	344	40.9
Real-time warning system – LMS	37	262	31.2

These calculations assume all individuals at risk for lightning exposure receive alerts from the new warning systems. A more realistic assumption (and a conservative one) would be that only some portion of the at-risk population is within earshot of the warning. For this benefits case, we assume 25 percent of those exposed to lightning receive the warnings, yielding the totals in Table 32, which were calculated similarly to the methods used in the Lincoln Lab report [Weber]. We also note that implementing a highly timely and location-specific lightning warning system is rapidly becoming less costly given the ubiquitous presence of cell phones and the increasing proportion of cell phones with location-sensing capabilities.

Table 32. Adjusted Fatalities, Injuries and Property Damages: Current vs. Real Time Warning System Scenarios (2003)

	Fatalities	Injuries	Property Damage
No Warning System	61	430	$51.1M
Warning System (no new Sensors)	58*	409	$48.6M
Warning System (LMS)	55	388	$46.1M

Calculated as: 61 - (25(61-49)). Similar methodology was applied to injuries and property damages, and for the LMS scenario as well.

From Table 32, the marginal improvements of the LMS over a warning system using today's sensor are: 3 fatalities, 21 injuries, and $2.5M in property damage.

Assigning Dollar Values

Using the Federal Aviation Administration's conservative proxy for economic value of life lost of $2.97M (2003) [Federal Aviation Administration], we derive economic benefits with a GOES-R LMS of approximately $8.9M per year (2003$) from reduced fatalities caused by lightning.

While exact costs associated with lightning injuries can vary, this benefits assessment bases cost estimates on the documented 2001 story of Michael Utley, an amateur golfer who was hit by lightning that blew his shoes off and stopped his heart [Galle]. Utley spent 38 days in intensive care and nearly 3 months in physical rehabilitation [NOAA and PGA Tour Public Alert]. And according to Dr. Mary Ann Cooper, director of the Lightning Injury Research Program at the University of Illinois at Chicago, Utley's story mirrors the 90 percent of lightning-strike victims who survive [NOAA and PGA Tour Public Alert]. Just basing injury cost estimates on these 38 days of intensive care, at $2000-$3000 per day (Aldridge) yields direct costs of $95,000. Add in other costs including rehab, ongoing impact to quality of life, and costs of emergency personnel and transportation, and we estimate that conservatively, costs could easily exceed $254,500 per injury (2003). Using this rate, we estimate that lightning injuries that impose costs of roughly $5.3M per year could be avoided with a GOES-R LMS.

Finally, based on the assumptions, constraints, and figures laid out above, and assuming savings of $2.5M of property damage, a total of nearly $16.7M in lightning-related costs could be avoided annually with a new warning system based on a GOES-R Lightning Mapper Sensor (Table 33). When benefits are calculated over the 2015-2029 period using a 7 percent discount rate, they total $72.3.

Table 33. Cost Avoidance with GOES-R LMS $M (2003)

	Fatalities	Injuries	Property Damage	Total
Warning System (LMS)	$8.9	$5.3	$2.5	$16.7

Additional Benefits

The Lincoln Lab Lightning Mapper Sensor study from 1998 also assesses benefits related to avoiding economic disruptions from lightning ground strikes. The two key areas of focus are the impacts that reductions in lightning advisories and length of watch periods have on (1) the electric power generation and distribution industries, and (2) Space Shuttle operations. Only the electric power estimate is included in the total, while the Space Shuttle operations case is presented only as an example.

<u>Electric Power</u>

Lightning is responsible for approximately 50 percent of the power failures in regions of the U.S. where thunderstorms are most active, costing U.S. electric utility companies as much as $1B per year in damaged equipment and lost revenue [Diels]. The electric power industry can realize savings from more accurate lightning advisories in 2 key ways: (1) more efficient pre-positioning and dispatching of repair crews to impacted or at-risk locations, which reduces labor costs and outage times, and; (2) reduced watch periods that lead to more efficient use of expensive alternative power generation options pursued in response to the threat of lost overhead transmission lines due to lightning.

The 1998 Lincoln Lab report assess potential cost savings related to the latter. Using available data on the number of utility companies and power plants in the U.S., their average hourly cost of maintaining a watch advisory, previously observed cost savings from better use of existing lightning data at Con Edison, and assumptions regarding use of more expensive generation or transmission modes, the Lincoln Lab report estimates incremental benefits from the use of LMS data. By reducing the length of watch periods an additional 5 minutes over current systems, a GOES-R Lightning Mapper Sensor could generate $8.2M in additional annual cost savings (2003) for the nation's electric utilities.

Since this calculation only estimates benefits for one of the above-mentioned cost savings options, it is, by definition, a conservative estimate of the true benefits to electric utilities from more accurate and timely lightning advisories.

Kennedy Space Center

With the 2000-3000 cloud-to-ground lightning strikes per year that occur within 5 nm of the NASA Kennedy Space Center (KSC) and Cape Canaveral Air Station, the accuracy of lightning hazard warnings and advisories for these facilities is critical. Increased accuracy leads to improved personnel safety, increased productivity from less unnecessary labor down time, and better-informed launch decisions. The Lincoln Lab study reviews previous research on observed accuracy improvements in the issuing and canceling of advisories/warnings stemming from the use of total lightning data from the KSC Lightning Detection and Ranging (LDAR) system. The report calculates annual savings possible from one institution (NASA KSC) from one program element (Space Shuttle ground processing). Using the reduction in the number of advisory hours (from the use of improved lightning data), the number of base personnel impacted by each advisory, and their average hourly labor rate, the study calculates that yearly estimated savings of $20.2M (2003) with an NPV of $87.4M for this one application alone are realized through the total-lightning based LDAR advisory system.

These savings estimates are extremely conservative for two key reasons. They do not include the considerable savings to the nation's many other commercial and DOD launch programs—only to Kennedy Space Center's Space Shuttle ground processing. And the analysis does not include potential savings from earlier termination of the end of storm threat, which some in the industry believe could be as large as the savings from the initial issuance of the advisory.

Summary: Benefits from Improved Lightning Forecast Accuracy

Overall, benefits to the U.S. economy from LMS-related improved lightning forecast accuracy could total nearly $25M per year (2003$), with a net present value of nearly $108M when benefits are calculated over the 2015-2029 period using a 7 percent discount rate (Table 34).

Table 34. Incremental Annual Savings of Lightning Ground Strike Related Costs from LMS $M (2003)

Benefit Area	Savings
Improved safety (reduced lightning deaths/injuries/property damage)	$ 16.7
Electric utility savings from reduced watch periods	$ 8.2
Total Annual Savings	$ 24.9
NPV of total (2015-2029)	$107.7

Finally, for the many reasons indicated above, this benefits estimate is extremely conservative. Indeed, the savings realized at Kennedy Space Center alone, from implementing a total-lightning based advisory process utilizing the LDAR system to improve the accuracy of lightning advisories doubles the benefits figure for this entire lightning case. While further *incremental* benefits from LMS would likely represent a portion of these observed savings, expanding the total lightning based advisory process to other commercial and DOD launch programs would likely increase benefits significantly.

Section 3

Conclusions

About $4 trillion of the annual United States Gross Domestic Product is weather sensitive. The GOES satellite system, with a unique vantage point, plays a key role in continuously monitoring a wide variety of environmental phenomena and providing weather data used to generate a wide variety of products and forecasts. NOAA plans to launch these satellites with new and improved instruments in the 2012 time frame. The GOES-R imager and HES sounder instruments represent a substantial step forward in spatial, spectral, and temporal resolution compared with the current imager and sounder. NOAA expects that these new sensors will significantly improve the capability of the United States to detect, monitor, track and forecast weather phenomena of great importance to the nation.

It is important to recall that the case studies developed and presented in this paper represent just a sampling of economic sectors and domains from which economic benefits can be realized. The total *annual* marginal benefits from these five cases are approximately $599M with discounted present value (over the GOES-R series lifecycle) of approximately $2.6B. These benefits, along with the benefits presented in the Phases I and II report (along with the consumer benefits of drinking water) are approximately $1.5B annually with a discounted present value in excess of $7.1B.

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Acronyms

ABI	Advanced Baseline Imager
ASA	American Sportfishing Association
AVHRR	Advanced Very High Resolution Radiometer
AVN	Aviation
B	Billion(s)
CBA	Cost/Benefit Analysis
CONU.S.	Continental United States
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GOES	Geostationary Operational Environmental Satellite System
HES	Hyperspectral Environmental Sounder
IC	Intracloud
KSC	Kennedy Space Center
LDAR	Lightning Detection and Ranging
LMS	Lightning Mapper Sensor
M	Million(s)
MGD	Million Gallons per Day
MPC	Marine Prediction Center
MSA	Magnuson-Stevens Fishery Conservation Management Act
MSY	Maximum Sustainable Yield
NARUC	National Association of Regulatory Utility Commissioners
NESDIS	National Environmental Satellite, Data, and Information Service
NLDN	National Lightning Detection Network
NMFS	National Marine Fisheries Service

Nm	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Navy Operational Global Atmospheric Predication System
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPV	Net Present Value
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OMB	Office of Management and Budget
PGA	Professional Golf Association
PLCAA	Professional Lawn Care Association of America
POES	Polar-orbiting Operational Environmental Satellite
PV	Present Value
SFA	Sustainable Fisheries Act
SST	Sea Surface Temperature
TEU	Twenty-foot Equivalent Unit
TPW	Total Precipitable Water
U.S.GS	United States Geological Survey
WTO	World Trade Organization